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Effects of nitrogen fertilization on the abundance of soil fauna populations in a Scots pine stand

Effekter av kvävegödsling på abundansen av markfaunapopulationer i ett tallbestånd

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ABSTRACT

Two pilot studies and one main study were performed in 1971 to observe the effects of forest fertilization on the abundance of enchytraeids and microarthropods in a young stand of Scots pine. After treatments of 60 kg N per hectare in 1969 and 1970 and 40 kg N per hectare in 1971 (all treatments given as ammonium nitrate) no marked effects on the abundance could be detected in the main sampling which was performed about 5 months after the last application. When the three annual applications were 180, 180, and 120 kg N per hectare the abundances of Enchytraeidae, Collembola and Oribatei decreased significantly. These annual applications are on about the same level as those used in practical forestry, while a total application of 480 kg N per hectare is considerably above present practical use.

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1. INTRODUCTION

In Sweden forest fertilization on a practical scale started during the 1960's. During the period 1962 - 1969 approximately 430 000 hectares of productive coniferous forests were fertilized with nitrogen (Holmen, 1970). In the beginning the nitrogen was applied in the form of urea but now ammonium nitrate is mostly used. The mean dosage has increased from 61 kg nitrogen per hectare in 1962 to 132 kg per hectare in 1970 (Friberg, 1971).

The effect of forest fertilization on the abundance of soil fauna populations has been studied by Huhta _et al._ (1967, 1969) in Finland and by Abrahamsen (1970) in Norway. Huhta _et al._ (_op. cit._) have followed the number of soil animals in a Scots pine (_Pinus silvestris_ L.) stand during 5 1/2 years after application of a NPK-fertilizer. The nitrogen component corresponded to about 90 kg per hectare. The application of the fertilizer first caused a reduction in the numbers of soil animals, but during the second and third years the abundance increased especially of Enchytraeidae and Collembola. After 5 1/2 years there were still 80 per cent more Enchytraeidae in the fertilized plots than in the controls. The number of Collembola was then insignificantly less in the fertilized than in the control plots. Oribatei and other Acari did not show such marked differences as Enchytraeidae and Collembola.

Abrahamsen (_op. cit._) has studied the effect of urea fertilization on different species of Enchytraeidae in a mixed spruce and pine forest. He used three dosages of urea corresponding to 100, 400 and 1600 kg nitrogen per hectare. Fertilization with 100 kg nitrogen did not markedly affect the abundance of the dominant enchytraeid _Cognettia sphagnetorum_. During the period immediately following fertilization with 400 kg the abundance decreased, but after 2 - 3 years the abundance of _C. sphagnetorum_ increased and became even greater than in the control plots. When 1600 kg were applied the abundance decreased at the beginning and remained on a very low level throughout the investigation period of four years.

The aim of our work was to study the effects of different dosages of ammonium nitrate on the abundance of enchytraeids and microarthropods in a young stand of Scots pine. First, however, a pilot study was made on May 12 in 1971 to see if there were any recognizable differences between a plot treated with a high dosage of a NPK-fertilizer and a control plot. A second pilot study was made on August 25 in 1971, when two plots treated with different dosages of ammonium nitrate were compared with a control plot. Reports on both of these pilot studies are briefly given here. A more thorough study was made on October 12 in 1971 when the effects on the soil fauna of different dosages of ammonium nitrate were compared. On that occasion the sampling of soil fauna was carried out about five months after the last application of fertilizer.

2. STUDY AREA

The study area (Lisselbo) is situated about 25 km SW of Gävle in Sweden. It is located about 80 metres above sea level, facing west on a slightly sloping side of a glacifluvial eskar. The height difference between the top of the eskar and the surroundings is not more than five to ten metres. The soil type is a podzol with a rather thin mor layer. The soil is sandy and well drained throughout the area. The texture of the sand varies from gravelly to fine sandy. The annual precipitation is about 600 mm.

On January 4 in 1954 the former pine forest on the eskar was felled by a storm. A certain number of self-sown pine seedlings occurred within the area, but in addition the area was planted with pine in 1955 and in 1966 the spacing of the young stand was regulated by removing a number of trees. In 1971 the pines were about five metres in height.

The vegetation in the field layer is dominated by *Calluna vulgaris* (L.) Hull., *Empetrum nigrum* L., *Vaccinium vitis-idaea* L., *Festuca ovina* L. and *Descampsia flexuosa* (L.) Trin. The bottom layer consists of *Dicranum* spp., *Pleurozium schreberi* (Brid.) Mitt., *Cetraria islandica* (L.) Ach. and *Cladonia* spp.

At Lisselbo, C O Tamm and collaborators (Royal College of Forestry, Stockholm) have laid out optimum nutrition experiments concerning pine growth (Tamm, 1973). One of these experiments (E 40) is a nitrogen dosage experiment with four replicates (blocks no. I-IV) and with various nitrogen levels given either alone or together with phosphorus and potassium. Each block consists of one control plot and seven plots with different treatments. Each plot, 20x20 m, is surrounded by a 5 m wide buffer strip treated in the same way as the plot. All the soil fauna samples mentioned below were taken in plots belonging to experiment E 40.

3. METHODS

The first pilot sampling was made in May 1971 when samples for soil fauna extraction were taken from a plot with a high dosage of NPK and a control plot. The NPK-plot and the control plot lay close to each other and belonged to the same block (no. II). They did not show any visible differences as regards soil structure. The amount given per hectare within the NPK plot was 180 kg nitrogen (given as ammonium nitrate), 40 kg phosphorus and 80 kg potassium in May 1969. In May 1970 it was again treated with 180 kg nitrogen but with no addition of PK-fertilizers. Fifteen sample units were taken at random along the inner margin of the buffer strips of each of the plots in order to save the net plots from destructive sampling.

The second pilot sampling was carried out in August 1971 in three plots. One plot was not treated (NO), the second was treated with 60, 60 and 40 kg nitrogen (N1) in May 1969, May 1970 and May 1971, respectively and the third plot was treated with 180, 180 and 120 kg nitrogen (N3) on the same occasions. The nitrogen was given as ammonium nitrate. Fifteen sample units were taken from each of the plots in the same way as in the May sampling. The plots belonged to the same block (no. III).

The main sampling which took place in October 1971 used the randomized blocks design (Snedecor & Cochran, 1968:299-301). Samples were taken from treatments NO, N1 and N3 in each of the four blocks. Five sample units were selected at random within each net plot. In N3 the number of microarthropod soil sample units were reduced to four because of limitations in extraction capacity.

At each sample point soil cores were taken to a depth of 10 cm for enchytraeids (surface area 33.2 cm^2) and microarthropods (surface area 10.8 cm^2). The soil cores were transported to the laboratory in polythene bags. Before extraction the soil cores were divided into 2 cm slices. The enchytraeids were extracted in a modified Baermann funnel (O'Connor, 1962) for three hours and the microarthropods were extracted in an extractor of Macfadyen's high gradient canister type (Macfadyen, 1961) for four days. Half the number of the microarthropod soil cores had to be stored for four days at +6°C before extraction. Storage for up to a week at temperatures of about 5°C is not considered to cause any serious changes in the number of animals in soil samples (Edwards & Fletcher, 1971). The Enchytraeidae, Collembola and some Acari were identified to the species level. The t-test was used to compare the different treatments as regards the soil fauna.

4. RESULTS

The estimated abundance of the soil fauna in the pilot sampling in May is shown in Table 1. The mean value and standard error (S.E.) is given for each of the species found. The abundances of Enchytraeidae, Collembola and Protura are significantly less in the NPK-treated plot than in the control plot, which is marked by the p-value according to the t-test.

The results of the pilot sampling in August are shown in Table 2. No significant difference was obtained between the plots with NO and N1 treatments. Enchytraeidae and Collembola were significantly fewer in the N3 plot than in the NO and N1 plots. Protura was less abundant in the N3 plot than in the N1 plot.

The main results of the October sampling are shown in Table 3. The mean number per square meter within each plot is given for dominant species and sub-groups of Enchytraeidae, Collembola, Protura and Acari. According to the t-tests the only significant effect of the N1 treatment was on the abundance of *Orchesella bifasciata*. The N3 treatment resulted in a significant decrease of Enchytraeidae, Collembola and Oribatei. Most of the population decrease could be attributed to some dominant species such as *Cognettia sphagnetorum*, *Tullbergia krausbaueri* and *Oppia* spp. The results are summarized in Figure 1.

The identified species from the Lisselbo samplings are listed in the appendix.

5. DISCUSSION

The pilot studies were made in order to elaborate hypotheses on effects of forest fertilization. The first pilot study showed that a high dosage of NPK possibly caused a decrease in the number of some soil animals. The second pilot study indicated the same effect for high dosages of nitrogen but not for moderate dosages. In both of these studies the effects of edaphic and other factors could not be separated from the effects of the treatment.

The sampling in October showed that the N3 treatment had caused a significant decrease in the abundances of Enchytraeidae, Collembola and Oribatei, which was not the case with the N1 treatment. The total application of nitrogen to the N1 plot was 160 kg per hectare, which is approximately the same as the dosage used at present in practical forestry, while the N3 plot had received 480 kg N per hectare. In both cases, however, the total amount of ammonium nitrate was not applied in one dosage as in practical forestry, but was applied in three annual treatments.

Increases in microbial populations after nitrogen fertilization have been demonstrated by, among others, Roberge & Knowles (1966). Most of the species recorded here are assumed to feed on the microflora and an increase in soil fauna populations would be expected. The decrease in some soil fauna populations as a response of the N3 treatment may be an effect of poisoning. The ammonium nitrate was applied to the soil surface as pellets and the salt concentrations might have been very high in some microhabitats in the soil when the first rainfall dissolved the pellets. The injurious effect to the soil fauna might have faded out once the salt solution had become more diluted. If this is a correct hypothesis then it is the annual dosages of 180 or 120 kg N per hectare that cause the harmful concentration rather than the total dosage, in this case 480 kg N per hectare over three years. In that case the dosages of ammonium nitrate used at present in practical forestry might affect the abundance of soil fauna.

The results presented in this report are mainly based on one sampling performed about 5 months after the last application of fertilizer. Nothing therefore can be said at present about the long-term influences of ammonium nitrate fertilization. The results are in agreement with those presented by Huhta _et al._ (_op. cit._) in Finland and Abrahamsen (_op. cit._) in Norway, even though they have used some other types of fertilizers.

6. SAMMANFATTNING

Effekter av kvävegödsling på abundansen av markdjurspopulationer i ett tallbestånd

Under 1971 utfördes två preliminära studier och en huvudstudie över effekter av skogsgödsling på abundansen av enchytraeider och mikroartropoder i ett ungt tallbestånd. Efter behandling med ammoniumnitrat motsvarande 60 kg N under 1969 och 1970 och 40 kg N per hektar under 1971 kunde inga påtagliga abundansförändringar visas 5 månader efter sista gödslingen. När de tre årliga doseringarna var 180, 180 och 120 kg N per hektar hade abundansen av enchytraeider, collemboler och oribatider minskat signifikant. Dessa årliga doseringar ligger på ungefär samma nivå som i praktiskt skogsbruk, medan den totala dosen av 480 kg N per hektar är avsevärt högre än vad som förekommer vid praktisk skogsgödsling.

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Table 1. Mean number ($\bar{x}$) and standard error (S.E.) per m^2 for enchytraeids and microarthropods in May 1971 in a NPK-treated plot and a control plot. The sample size was 15 in each plot. A significant difference between the plots is marked with the p-value.

	Control plot		NPK-treated plot		p-value
	$\bar{x}$	S.E.	$\bar{x}$	S.E.	
ENCHYTRAEIDAE					
Cognettia sphagnetorum	3400	900	200	100	p<0.005
COLLEMBOLA					
Hypogastrura inermis	1700	900	300	200	
Willemia aspinata	200	100	0		
W. anophthalma	1000	700	100	100	
Friesea mirabilis	1200	500	100	100	p<0.05
Pseudachorutes subcrassus	100	100	400	200	
Anurida pygmaea	3300	1500	2300	700	
Neanura muscorum	300	100	0		
Onychiurus absoloni	1000	600	100	100	
O. armatus	7600	2200	4400	1100	
Tullbergia krausbaueri	13600	5600	6100	2600	
Anurophorus laricis	2800	1000	100	100	p<0.05
A. binoculatus	100	100	100	100	
Folsomia quadrioculata	7700	1700	3700	1100	
Isotomiella minor	4800	1800	400	200	p<0.05
Isotoma cinerea	400	300	0		
I. notabilis	100	100	0		
Entomobrya nivalis	100	100	100	100	
Orchesella bifasciata	1000	500	0		p<0.05
Lepidocyrtus lanuginosus	900	300	900	300	
Entomobryidae spp.	3400	1800	7600	6000	
Neelus minimus	0		100	100	
Sminthuridae sp.	0		100	100	
Collembola, total	51000	10400	26700	6100	p<0.05
PROTURA					
Eosentomon spp.	11400	2400	3700	900	p<0.01
SYMPHYLA					
Symphylella sp.	300	200	0		

Table 2. Mean number ($\bar{x}$) and standard error (S.E.) per m^2 for enchytraeids and microarthropods in August 1971 in plots treated with NO, N1 and N3 (see text). The sample size was 15 in each plot. A significant difference between the NO and N3 plots is marked with the p-value.

	NO		N1		N3		p-value
	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	
ENCHYTRAEIDAE							
Cognettia sphagnetorum	3900	1100	5400	2000	500	300	$p<0.01$
COLLEMBOLA							
Hypogastrura inermis	400	300	1500	900	0		
Willemia aspinata	0		500	300	0		
W. anophthalma	700	700	0		0		
Friesea mirabilis	600	300	300	300	0		$p<0.05$
Odontella lamellifera	0		100	100	0		
Pseudachorutes subcrassus	0		100	100	0		
Anurida pygmaea	3500	700	6700	3800	7300	2500	
Neanura muscorum	200	200	400	300	100	100	
Onychiurus absoloni	200	200	0		0		
O. armatus	26000	17200	10700	2800	3600	1100	
Tullbergia krausbaueri	46600	8900	21200	4600	17700	2900	$p<0.01$
Anurophorus laricis	3800	1300	800	400	600	300	$p<0.05$
A. binoculatus	0		1200	800	500	400	
Folsomia quadrioculata	100	100	10300	4400	400	300	
Isotomiella minor	5000	1500	2400	600	2400	1400	
Isotoma violacea	0		200	200	0		
Entomobrya nivalis	100	100	0		0		
Orchesella bifasciata	700	400	500	400	400	300	
Lepidocyrtus lanuginosus	100	100	0		0		
Entomobryidae spp.	2500	600	2500	700	1300	500	
Dicyrtoma fusca	0		300	200	200	100	
Bourletiella cf. viridescens	0		100	100	0		
Sminthurus lubbocki	100	100	700	500	0		
Collembola, total	90600	20300	60400	10000	34400	4300	$p<0.05$
PROTURA							
Eosentomon spp.	16000	6600	19100	3300	6700	1500	
SYMPHYLA							
Symphylella sp.	400	200	400	300	400	200	
PAUROPODA							
Pauropoda sp.	100	100	0		0		

Table 3. Mean number per m^2 of dominant species and major groups of enchytraeids and microarthropods in October 1971. The mean numbers are given for each plot with the treatments N0, N1 and N3 (see text) within each block. A significant difference between N0 and N3 is marked with the p-value according to the t-tests.

	Block	I	II	III	IV	Mean	p-value
ENCHYTRAEIDAE							
Cognettia sphagnetorum							
	N0	4000	9800	7300	4300	6400	
	N1	8400	5500	4900	6400	6300	
	N3	1000	800	1400	1100	1100	$p<0.01$
COLLEMBOLA							
Anurida pygmaea							
	N0	3300	4600	6700	3500	4500	
	N1	4600	4400	2200	9400	5200	
	N3	6300	7900	3700	2800	5200	
Onychiurus armatus							
	N0	10600	12200	38900	7800	17400	
	N1	3900	12800	5000	12200	8500	
	N3	4900	1600	12500	6700	6400	
Tullbergia krausbaueri							
	N0	29300	20000	56300	71300	44200	
	N1	15200	31300	19600	34800	25200	
	N3	8300	15300	18100	8100	12400	$p<0.05$
Anurophorus laricis							
	N0	2000	3100	2800	13300	5300	
	N1	0	0	0	2400	600	
	N3	900	0	0	500	300	$p<0.05$
Folsomia quadrioculata							
	N0	2400	10400	0	0	3200	
	N1	11100	6900	6900	700	6400	
	N3	0	1600	1400	0	800	
Isotomiella minor							
	N0	1700	3700	5400	10000	5200	
	N1	200	3000	1500	600	1300	
	N3	1200	900	500	900	900	$p<0.05$
Orchesella bifasciata							
	N0	1500	1300	400	3000	1500	
	N1	400	0	0	900	300	
	N3	200	200	200	200	200	$p<0.05$
Collembola, total							
	N0	51700	55900	112400	113100	83300	
	N1	38000	60000	36700	62200	49200	
	N3	22900	29400	37300	22500	28000	$p<0.01$

Table 3. (continued)

	Block	I	II	III	IV	Mean	p-value
PROTURA							
Eosentomon spp.							
	N0	6500	17200	20900	11300	14000	
	N1	6500	14600	21700	27400	17500	
	N3	3900	8300	7200	2300	5400	
SYMPHYLA							
Symphylella sp.							
	N0	0	0	600	200	200	
	N1	0	900	400	200	400	
	N3	0	0	200	0	100	
ACARI							
Gamasina spp.							
	N0	1900	8000	6300	5000	5300	
	N1	6700	8300	9600	7800	8100	
	N3	7900	7200	1600	4600	5300	
Prostigmata spp.							
	N0	32200	31100	36900	45000	36300	
	N1	31500	25900	22400	50600	32600	
	N3	28700	67600	31300	33300	40200	
Astigmata spp.							
	N0	600	3900	1500	3000	2200	
	N1	9300	8900	3900	8300	7600	
	N3	3000	1600	200	1600	1600	
Brachychthoniidae spp.							
	N0	69400	64300	79600	35700	62300	
	N1	92200	98100	28900	105900	81300	
	N3	83600	43500	40700	23400	47800	
Camisiidae spp.							
	N0	5400	5900	8100	11700	7800	
	N1	5200	13100	2400	1900	5600	
	N3	2500	7600	200	900	2800	
Oppia spp. (adults)							
	N0	36700	57200	36100	91100	55300	
	N1	35000	26900	29600	54800	36600	
	N3	24800	26600	18000	24300	23400	$p<0.05$
Tectocepheus velatus							
	N0	25900	59100	59300	26500	42700	
	N1	27800	3900	73500	30700	34000	
	N3	6900	31000	50700	41700	32600	
Scheloribates spp. (adults)	N0	400	5700	1100	0	1800	
	N1	0	900	0	0	200	
	N3	0	0	0	0	0	
Phthiracaridae spp.							
	N0	700	700	900	1700	1000	
	N1	1100	1900	5900	1300	2500	
	N3	1200	1400	1900	700	1300	

Table 3. (continued)

	Block	I	II	III	IV	Mean	p-value
Oribatei, undetermined larvae and nymphae	N0	71300	95700	103000	151900	105500	
	N1	84600	49100	46700	124600	76300	
	N3	81000	72000	89800	30100	68200	
Oribatei, total							
	N0	210900	298700	295700	320700	281500	
	N1	255000	206100	232800	325700	254900	
	N3	211600	185400	218100	130300	186300	$p<0.05$
Acari, total							
	N0	245600	341700	340400	373700	325300	
	N1	302600	249600	268700	392400	303300	
	N3	251200	261800	251400	169900	233600	

APPENDIX

Synopsis of identified species of enchytraeids and microarthropods at Lisselbo

ENCHYTRAEIDAE
- Cognettia sphagnetorum Vejdovsky
- Mesenchytraeus sp.

COLLEMBOLA
- Hypogastrura inermis (Tullberg)
- Willemia aspinata Stach
- W. anophthalma Börner
- Friesea mirabilis (Tullberg)
- Odontella lamellifera (Axelson)
- Pseudachorutes subcrassus Tullberg
- Anurida pygmaea (Börner)
- Neanura muscorum (Templeton)
- Onychiurus absoloni (Börner)
- O. armatus (Tullberg)
- Tullbergia krausbaueri (Börner)
- Anurophorus laricis Nicolet
- A. binoculatus (Kseneman)
- Folsomia quadrioculata (Tullberg)
- Isotomiella minor (Schäffer)
- Isotoma cinerea (Nicolet)
- I. notabilis Schäffer
- I. violacea Tullberg
- Entomobrya nivalis (Linné)
- Orchesella bifasciata Nicolet
- Lepidocyrtus lanuginosus (Gmelin)
- Bourletiella cf. viridescens Stach
- Sminthurus lubbocki Tullberg
- Dicyrtoma fusca (Lucas)

PROTURA
- Eosentomon transitorium Berlese
- E. germanicum Prell

SYMPHYLA
- Symphylella cf. vulgaris Hansen

ACARI
- Mesostigmata
  - Parazercon sarekensis Willmann
  - Zercon sp.
  - Rhodacarus coronatus Berlese
  - Pergamasus lapponicus Trägårdh
  - Veigaia nemorensis (C.L.Koch)
  - V. cerva (Kramer)
- Prostigmata
  - Pyemotidae sp.
  - Nanorchestes arboriger (Berlese)
  - Rhagidia sp.
  - Tydaeidae sp.
  - Eupodes sp.
  - Linopodes sp.
  - Stigmaeidae sp.
  - Cheyletidae sp.
  - Bdella sp.
  - Cunaxa cf. setirostris (Hermann)
  - Tetranychidae sp.

APPENDIX (continued)

Astigmata
- Schwiebea cf. cavernicola Vitzthum
- S. cf. nova (Oudemans)

Cryptostigmata (Oribatei)
- Palaeacarus hystricinus Trägårdh
- Gehypochthonius sp.
- Brachychthonius sp.
- Sellnickochthonius zelawaiensis (Sellnick)
- Liochthonius sp.
- Nanhermannia nana Nicolet
- Nothrus silvestris Nicolet
- Platynothrus peltifer (C.L.Koch)
- Porobelba spinosa (Sellnick)
- Adoristes ovatus (C.L.Koch)
- Liacarus sp.
- Furcoribula furcillata (Nordenskiöld)
- Carabodes femoralis (Nicolet)
- C. labyrinthicus (Michael)
- C. marginatus (Michael)
- C. areolatus Berlese
- Tectocepheus velatus (Michael)
- Suctobelba subtrigona (Oudemans)
- Autogneta trägårdhi Forsslund
- Oppia nova (Oudemans)
- O. cf. falcata (Paoli)
- O. subpectinata (Oudemans)
- Caleremaeus monilipes (Michael)
- Oribatula tibialis (Nicolet)
- Scheloribates confundatus Sellnick
- S. laevigatus (C.L.Koch)
- Trichoribates trimaculatus (C.L.Koch)
- Galumna lanceata (Oudemans)
- Pelops duplex Berlese
- Tropacarus carinatus (C.L.Koch)
- Steganacarus striculus (C.L.Koch)
- Phthiracarus piger (Scopoli)
- Euphthiracarus cribrarius (Berlese)
- Rhysotritia ardua (C.L.Koch)

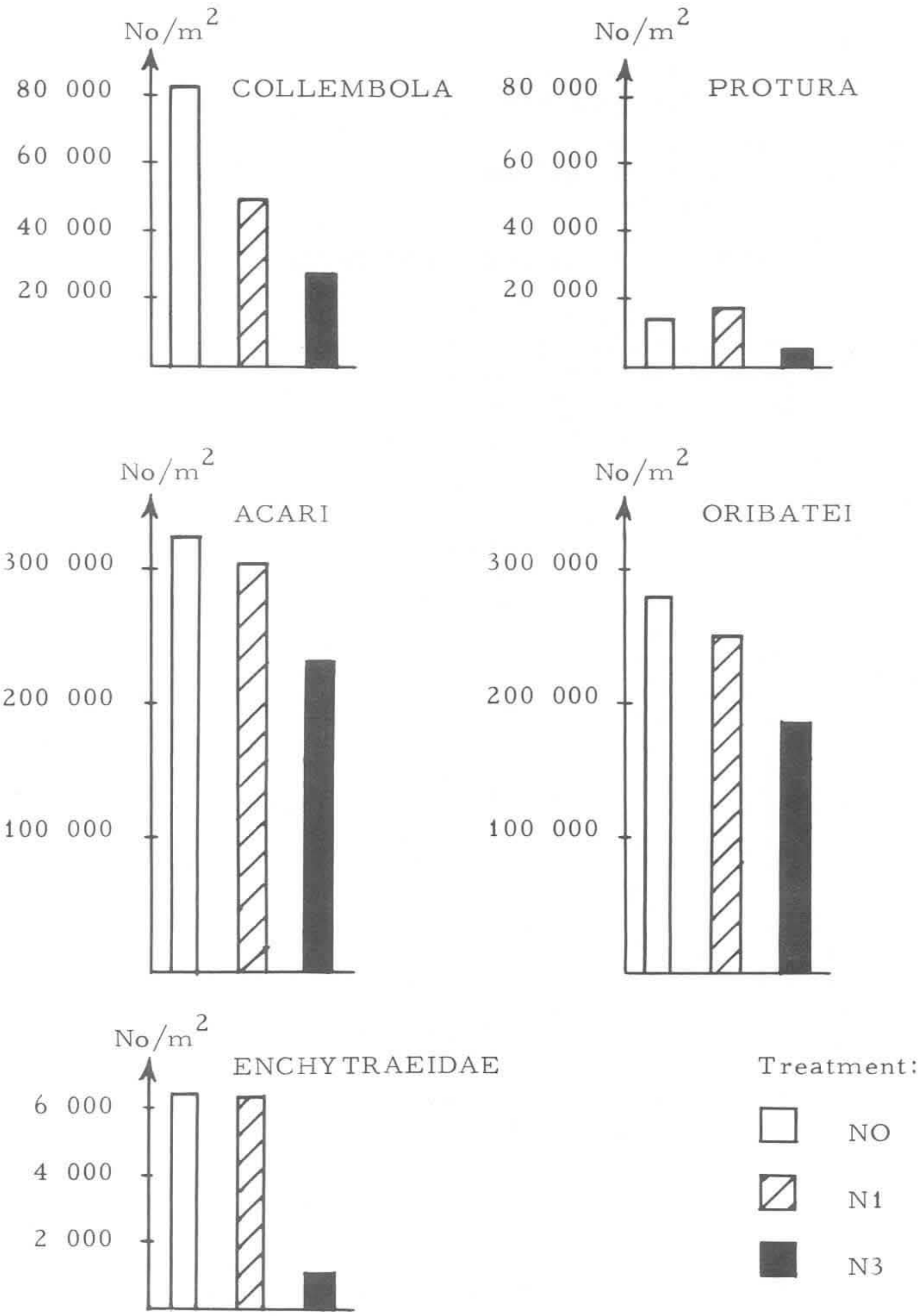

Fig. 1. Overall effects of treatments, October 1971 at Lisselbo.
Total number of animals per m^2.